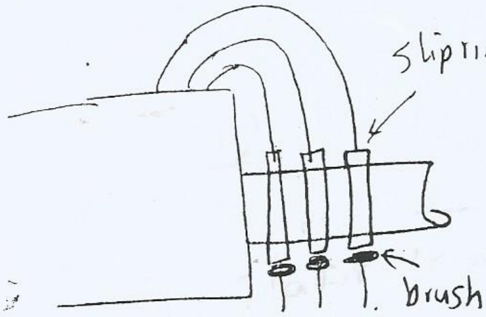
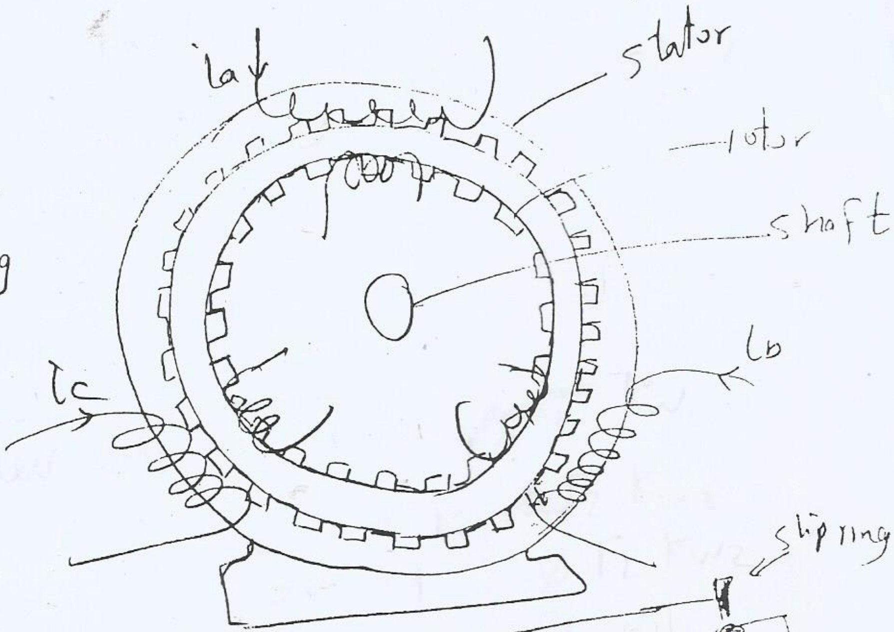
Three-phase Induction motor

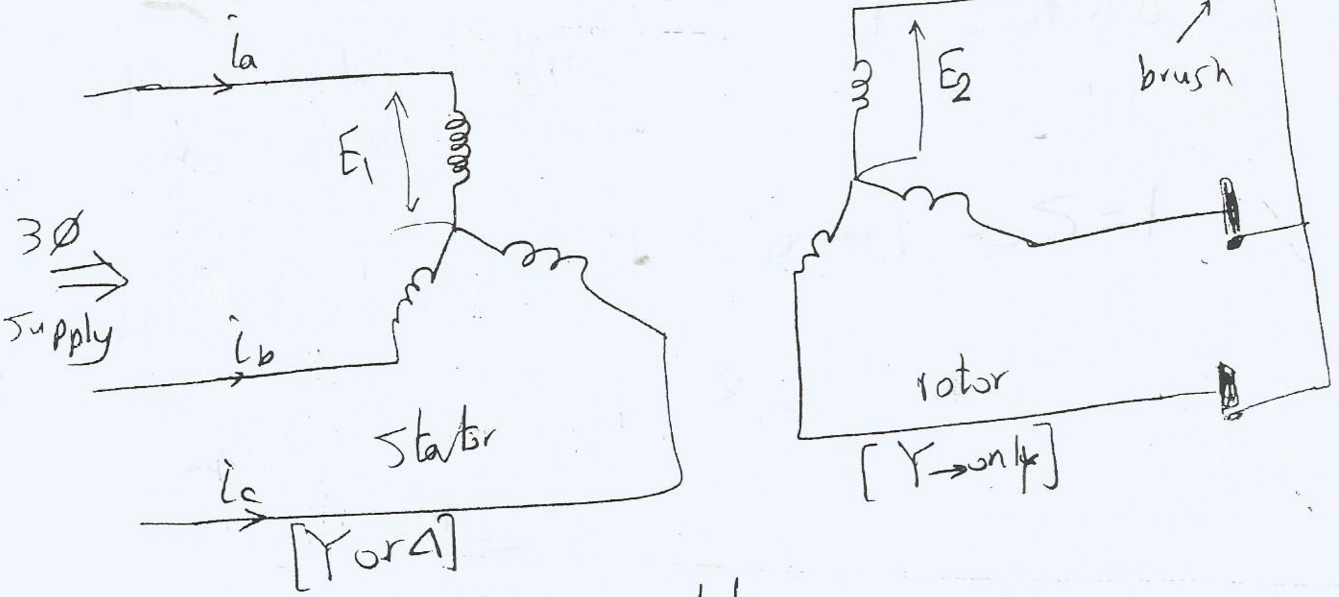
Done

two types of I.M
1] wound rotor [slip ring] type
2] squirrell cage rotor type

Slipring I.M







$$\text{Rotating Flux} \xrightarrow[\text{by}]{\text{rotate}} n_s$$

n_s = Sychronous speed $= \dfrac{60 f_1}{P}$ (rpm)

n = motor [shaft] speed (rpm)

$2p$ = number of poles
f_1 = Supply frequency (HZ)
f_2 = rotor frequency (HZ)

$$slip = S = \frac{n_s - n}{n_s} < 1 \Rightarrow n = (1-S)\, n_s$$

$$\left.\begin{aligned} \omega &= \frac{2\pi n}{60} \ \text{rad/sec} \\ \omega_s &= \frac{2\pi n_s}{60} \ \text{rad/sec} \end{aligned}\right\} \quad \omega = (1-S)\,\omega_s$$

$$f_2 = S f_1$$

E_1 = stator induced emf $= 4.44\, f_1\, \phi\, T_1\, K_{w1}$

E_2 = rotor " " $= 4.44\, f_2\, \phi\, T_2\, K_{w2}$
$= 4.44\, S f_1\, \phi\, T_2\, K_{w2}$

T = number of turn [stator(1) & rotor(2)]
K_w = winding factor [" " "]

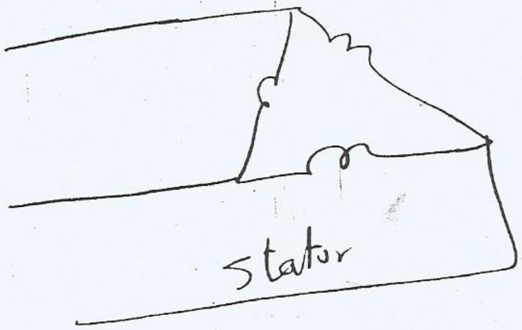
At stand still [rotor blocked] $\Rightarrow S = 1$

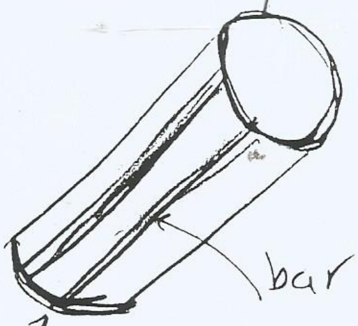
E_{20} = rotor emf at stand still
$= 4.44\, \underline{\underline{f_1}}\, \phi\, T_2\, K_{w2}$

$$E_2 = S E_{20}$$

$$\boxed{a = \frac{T_1 K_{w1}}{T_2 K_{w2}}}$$

☒ Squirrel Cage IM

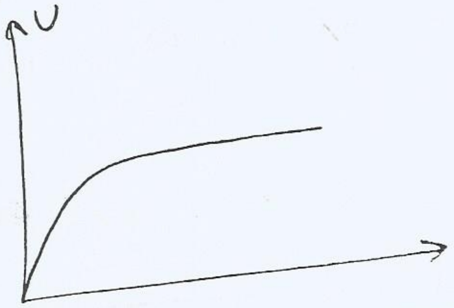




- Same Function of Slip ring IM.
- but no external rotor terminal
- used in small rating Application

☒ why must use Carbon brush in slip ring I.M

Carbon resistance represent non linear resistance as shown relation between voltage & current for brush resistance



⇒ constant voltage drop with increasing current

☒ why rotor must constructed as a Circle?

Circle give large Area with small Circumference, so saving in material and saving in copper ⇒ less copper losses ⇒ more efficiency

Starting of 3-phase I.M

$$I_2' = \frac{V_1}{\sqrt{(r_1 + r_2'/s)^2 + (X_1 + X_2')^2}}$$

$$\boxed{\begin{array}{l} I_{st} \propto V \\ T_{st} \propto V^2 \end{array}}$$

at starting $s = 1$

$$I_{2st}' = \frac{V_1}{\sqrt{(r_1 + r_2')^2 + (X_1 + X_2')^2}} = \text{Very large current}$$

So it must be reduce starting current by

1] using external rotor resistance [slip ring type]

2] reduce input stator voltage [slip ring & squirrel cage]

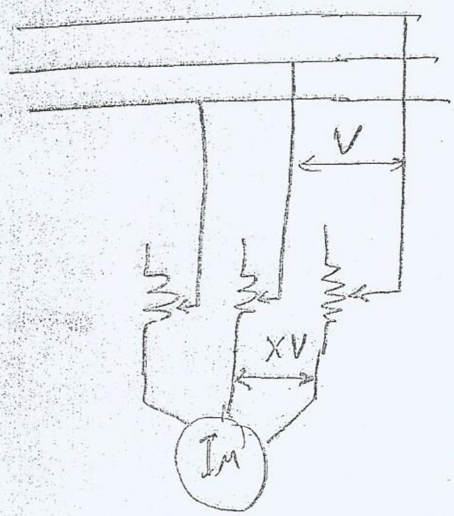
B starting of squirrel cage motors

1] direct switching

for small motor less than 10hp connected to infinite bus bar

2] Reduced input voltage

a] using series resistance

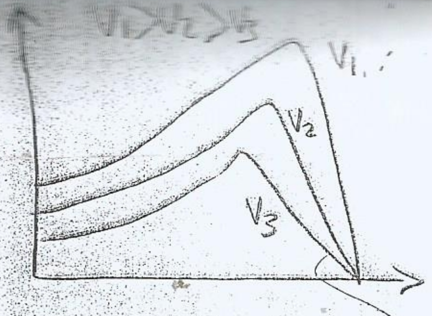


$$\frac{I_{st}|_{XV}}{I_{st}|_{V}} = X$$

$$\frac{T_{st}|_{XV}}{T_{st}|_{V}} = X^2$$

advantage

- reduce starting Current
- improve P.F at starting
- simple method



disadvantage

- reduce starting torque
- less efficiency method

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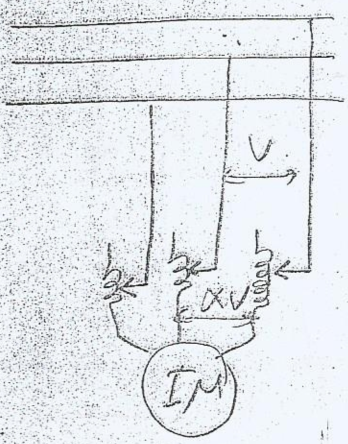
b) Using Series Reactor



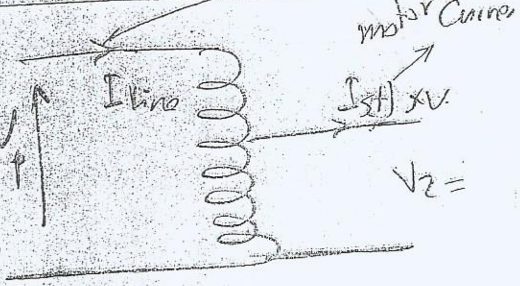
advantage

- reduce starting Current
- no copper loss
- high efficiency

disadvantage

- reduce starting torque
- low P.f

c) Auto transformer



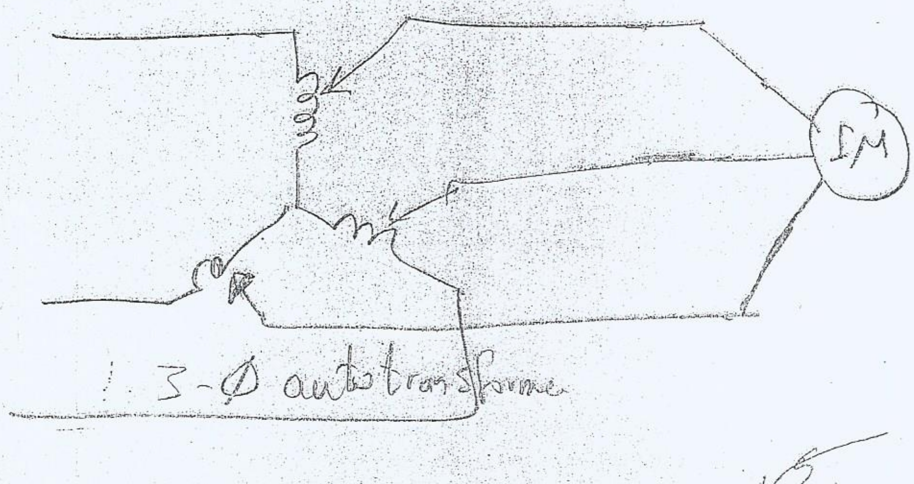
$$\frac{I_{st)xv}}{I_{st)v}} = x = \frac{V_2}{V_1}$$

$$\frac{I_{line}}{I_{st)xv}} = \frac{V_2}{V_1} = x$$

$$I_{line} = x \, I_{st)xv}$$

$$I_{line} = x^2 \, I_{st)v}$$

$$\frac{T_{st)xv}}{T_{st)v}} = x^2$$



3-Ø autotransformer

advantage
- reduce starting current
- no voltage drop across auto transformer
- high efficiency
- saving size [one wdg per phase]
- reduce line current at starting

disadvantage
- reduce starting torque
- more expensive method

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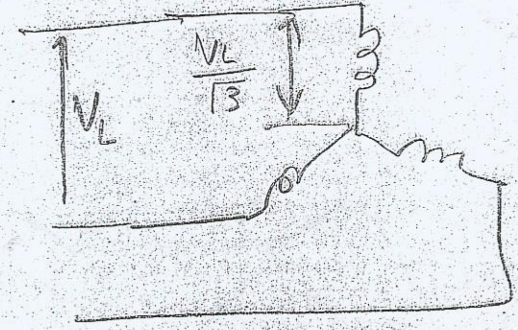
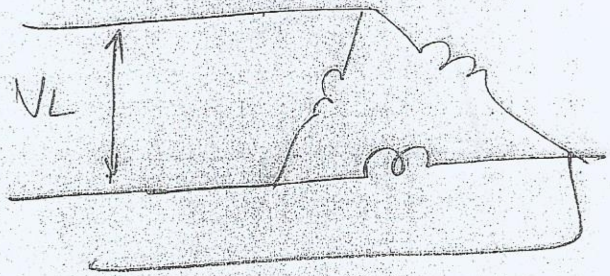
d] Y/Δ switch



At starting connect Y
At running connect Δ



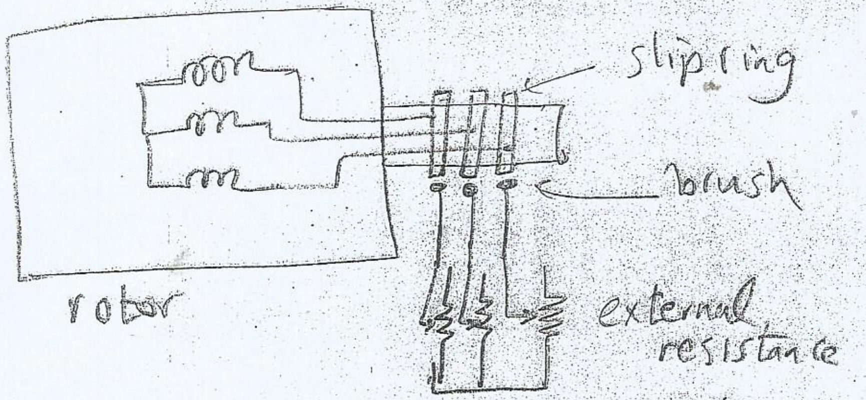
$$\frac{I_{st})_{xv}}{I_{st})_{V}} = \frac{1}{\sqrt{3}} = x$$

$$\frac{T_{st})_{xv}}{T_{st})_{V}} = \frac{1}{3} = x^2$$

advantage
- reduce starting current
- simple & cheap method
- no losses ⇒ high efficiency

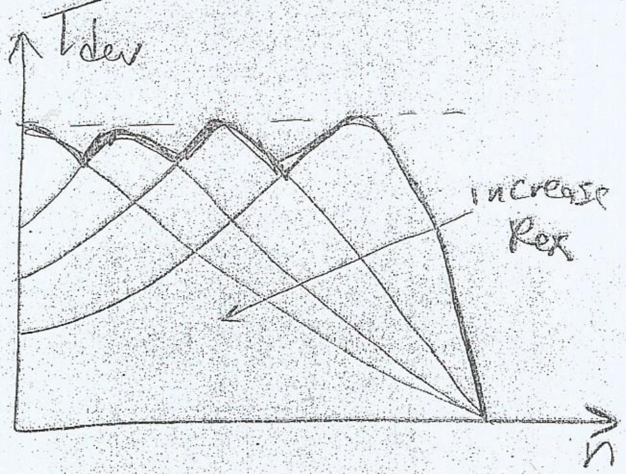
disadvantage
- reduce starting torque
- $x = 1/\sqrt{3}$ ⇒ constant

Starting of wound rotor [slip ring] I/M



- At starting, total external resistance connected to rotor circuit
- After starting Period, external resistance cut out in steps

$$I_{2st}' = \frac{V_1}{\sqrt{(r_1 + r_2' + R_{ex})^2 + (X_1 + X_2')^2}}$$



to achieve max torque at starting

$T_{max} = T_{st}$

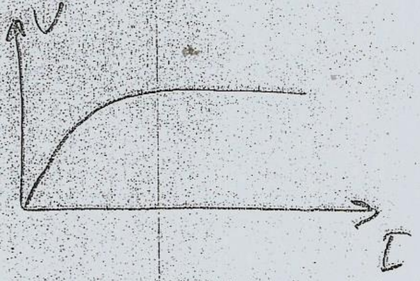
$\boxed{S_{mT} = 1}$ $\Rightarrow \frac{r_2' + R_{ex}}{\sqrt{r_1^2 + (X_1 + X_2')^2}} = 1$

<u>Advantage</u>
- reduce starting Current
- increase starting torque
- improve P.f

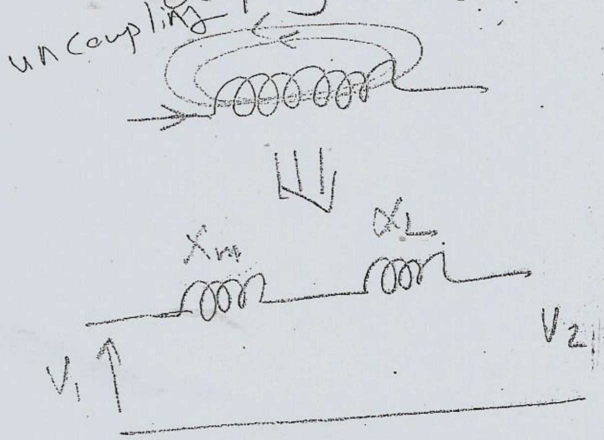
<u>disadvantage</u>
- large copper loss
- less efficiency

Why we use Carbon brush?

Carbon resistance non linear where its voltage-Current relation as shown So it has constant V.D at high current



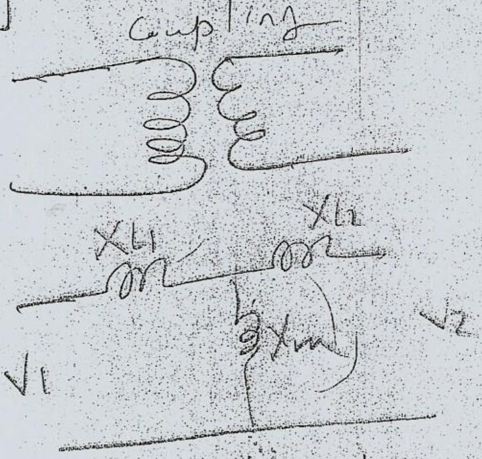
What's the diffrence between uncoupling coil & coupling coil [transformer]



X_m = magnetizing reactance

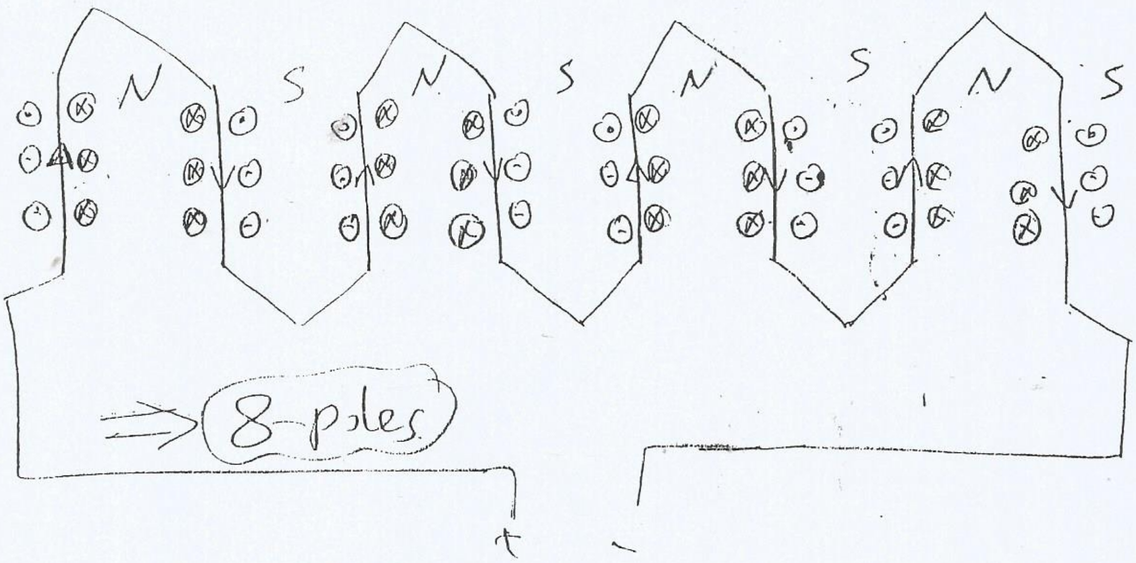
X_L = leakage reactance

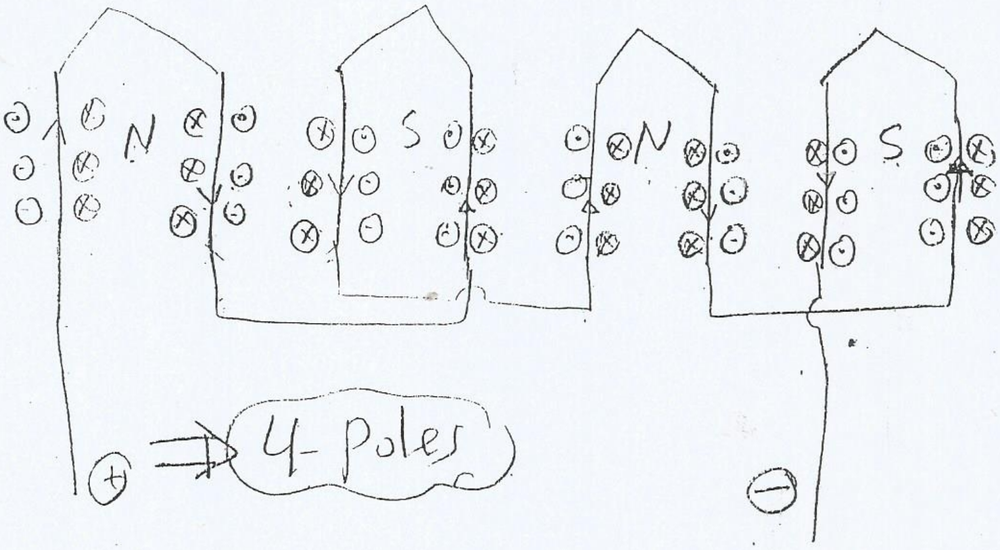
large Voltage drop in X_m, X_L



Small Voltage drop in X_{L1} & X_{L2}

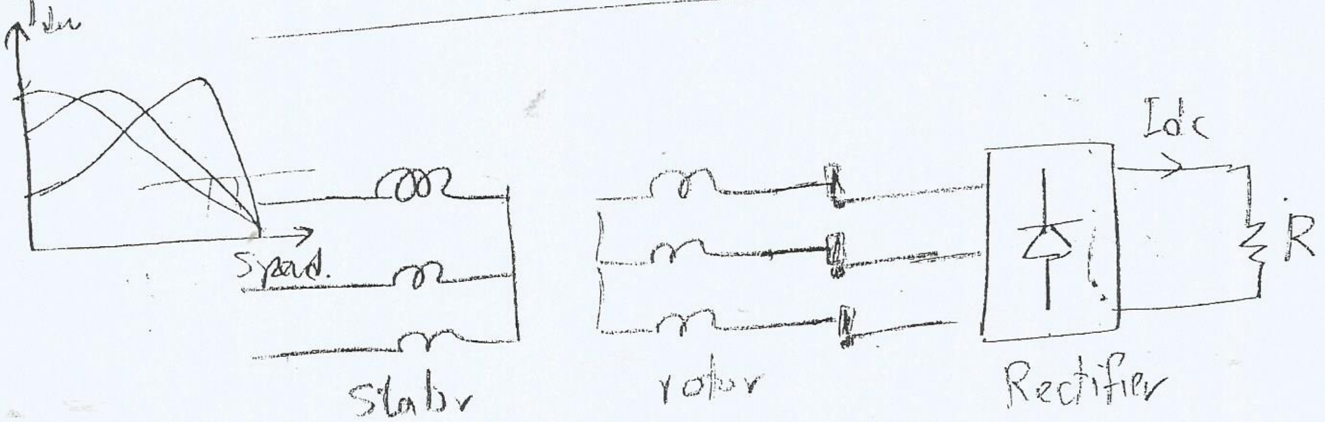
4] Change number of poles



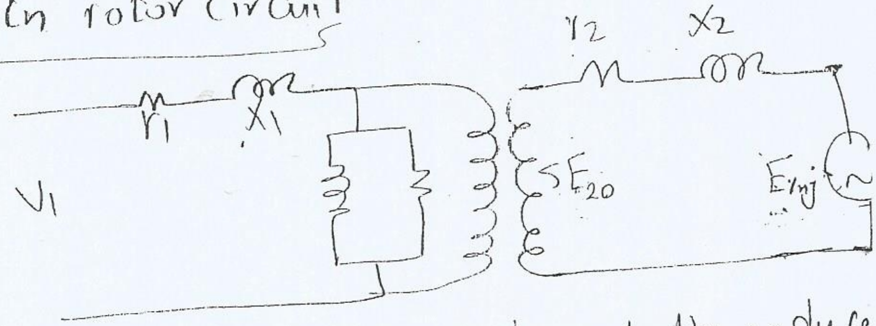


B] Slip ring Induction motor

1) by using external Rotor resistance



2] Injection voltage in rotor circuit



- when injection voltage is in phase opposition to the induce rotor emf it amounts to increasing rotor resistance.
  [subsychronous]
- when injection voltage is in phase with induced rotor emf it equivalent to decreasing rotor resistance.
  [supersychronous]

Induction generator [I.G]

- IM Can be used as a generator but it need Source of reactive Power as a Capacitor or it Can consume reactive power from the network.
- due to it's simplicity it widely used in wind turbine application.

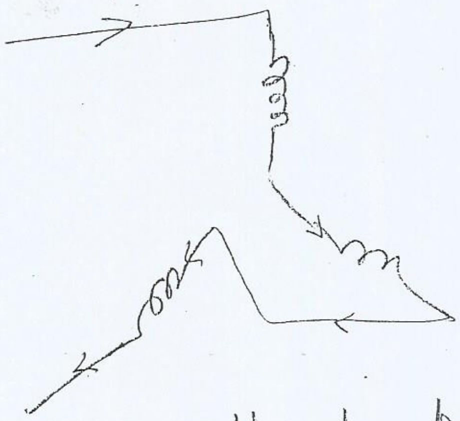
إنما لا يحتاج إلى صيانة دورية لعدم وجود عضو التوحيد [Commutator]

Braking

1] mechanical braking

2] Regenerative braking

the kinetic energy stored on the rotor mass may be returned to supply After Converting it from Dc to Ac by inverter circuit



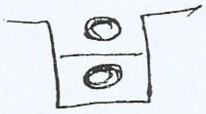
3] plugging

4] Single phasing

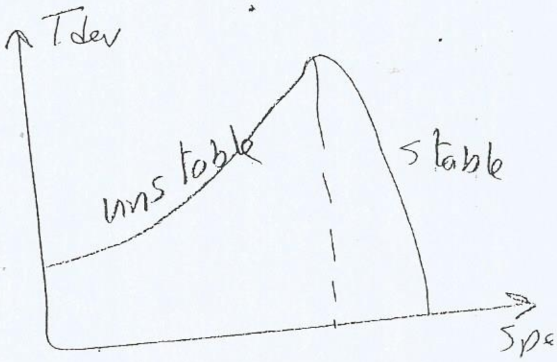
- Connect I.M as a single phase machine with single phase supply
- produce pulsating flux, so IM will not rotate

Using double layer windings

by using double layer windings, pitching of coil is possible $\Rightarrow$ advantage of chording



☒ squirrel cage I.M is considered constant speed machine



$$S = \frac{n_s - n}{n_s} = 5\% \longrightarrow 20\%$$

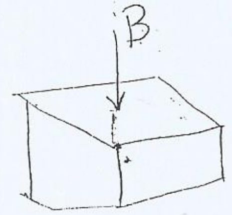
→ usually in normal I.M the slip ring from 5% to 20% so that the motor speed changes very little from no load to full load condition

→

e short notes about eddy current loss & hystresis loss

* for any conducting material. when external flux linked with the conducting material, eddy current will be circulated inside the material producing magnetic flux in reverse direction with external flux so total flux will be reduce

$$P_e = K_e F^2 B^2$$

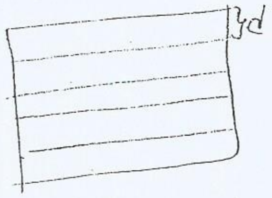


To reduce eddy current losses, use silicon steel lamination

⇒ high resistance ⇒ low current flow in the material.

$$P_e \propto d^2$$

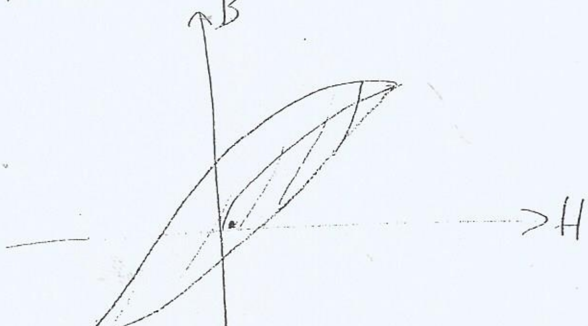
d = thickness



* for magnetic material the relation between flux density (B) and field intensity (H) as shown

⇒ there is a residual flux

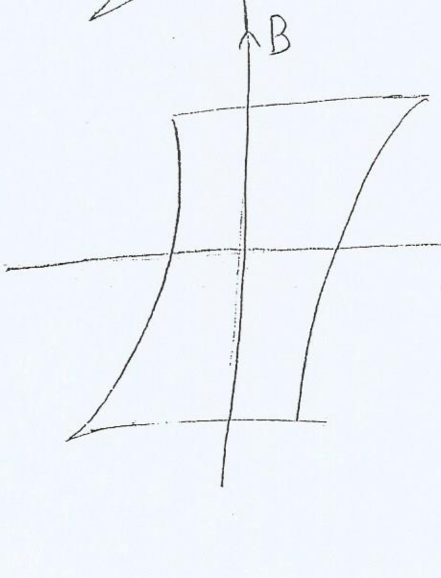
⇒ by increasing Area of the loop the hystresis loss increased



$$P_h = K_h F B^x$$

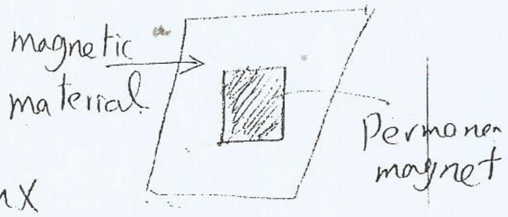
$X = 1.5 \longrightarrow 2.5$

taken $X \cong 2$



similar to Permenant magnet

why Permanent magnets stored by putting them on magnetic surface?



- To provide a path of the magnetic flux lines so that the magnetic flux from domain will be in the same direction.
- If magnet put in the air it loss it magnetic flux line in the air.

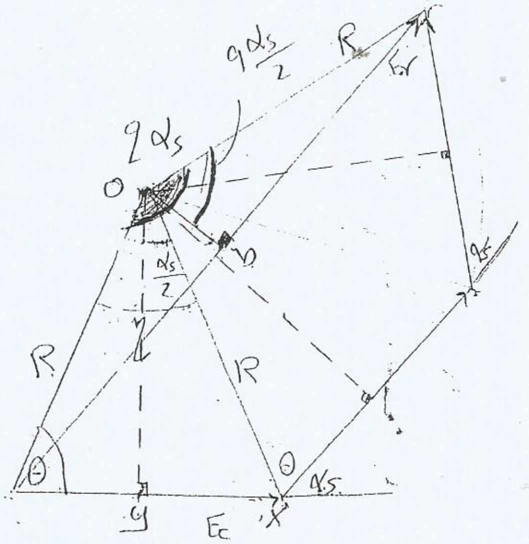
Disadvantages of using Aluminum in squirel cage IMs

Aluminum usually contain impurities due to that some bars in squirrel cage have a high resistance ⇒ low current path in these bars, so that the force not equal for all bars producing vibration

B Distribution Factor

$\cancel{\theta} + \alpha_s = \cancel{\theta} + 2$

$(\alpha_s = 2)$



$\Delta[oab]$

$\sin\left(q\frac{\alpha_s}{2}\right) = \frac{ab}{R}$

$E_r = 2ab$

$= 2 * R\sin\left(q\frac{\alpha_s}{2}\right)$

from $\Delta[oxy]$

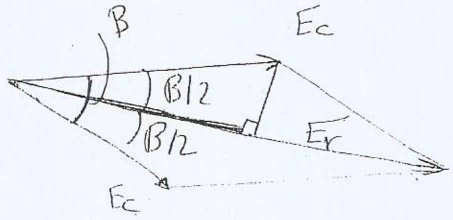
$\sin\left(\frac{\alpha_s}{2}\right) = \frac{E_c/2}{R} \Rightarrow R = \frac{E_c}{2\sin\left(\frac{\alpha_s}{2}\right)}$

$E_r = \cancel{2} * \frac{E_c * \sin\left(q\frac{\alpha_s}{2}\right)}{\cancel{2}\sin\left(\frac{\alpha_s}{2}\right)} = E_c \frac{\sin\left(q\frac{\alpha_s}{2}\right)}{\sin \alpha_s/2}$

$K_d = \frac{\text{vectorial sum}}{\text{algebric sum}} = \frac{E_r}{q E_c} = \frac{\sin(q\,\alpha_s/2)}{q\sin(\alpha_s/2)}$

$K_d = \frac{\sin(q\,\alpha_s/2)}{q\sin(\alpha_s/2)}$ حفظ

Chording Factor



$\frac{E_r}{2} = E_c \cos \beta/2$

$E_r = 2 E_c \cos \beta/2$

$K_p = \frac{E_r}{2 E_c} = (\cos \beta/2)$

$$S_{mt} = \frac{r_2'}{\sqrt{r_1^2 + (X_1 + X_2')^2}}$$

$$T_{dev} = \frac{3V_1^2 \, r_2'/s}{W_s\left[\left(r_1 + \frac{r_2'}{s}\right)^2 + (X_1 + X_2')^2\right]} = \frac{k/s}{\left(r_1 + \frac{r_2'}{s}\right)^2 + (X_1 + X_2')^2}$$

T_{max} when $\frac{dT_{dev}}{ds} = 0$

$$\frac{-\cancel{k}}{s^2}\left[\left(r_1 + \frac{r_2'}{s}\right)^2 + (X_1 + X_2')^2\right] - 2\left[r_1 + \frac{r_2'}{s}\right] * \left[\frac{-r_2'}{s^2}\right] \frac{\cancel{k}}{s} = 0$$

$$-\left[r_1^2 + \cancel{2r_1\frac{r_2'}{s}} + \left(\frac{r_2'}{s}\right)^2\right] + (X_1 + X_2')^2\Big] + \cancel{2r_1\frac{r_2'}{s}} + 2\left(\frac{r_2'}{s}\right)^2 = 0$$

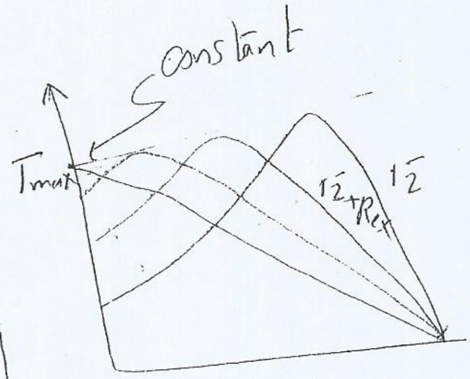
$$-r_1^2 + \left(\frac{r_2'}{s}\right)^2 - (X_1 + X_2')^2 = 0$$

$$\left(\frac{r_2'}{s}\right)^2 = r_1^2 + (X_1 + X_2')^2$$

$$\Rightarrow \frac{r_2'}{s} = \sqrt{r_1^2 + (X_1 + X_2')^2}$$

$$S = \frac{r_2'}{\sqrt{r_1^2 + (X_1 + X_2')^2}} = S_{mt} =$$ Slip at Max torque

$$T_{max} = \frac{3V_1^2 \, r_2'/S_{mt}}{W_s\left[\left(r_1 + \frac{r_2'}{S_{mt}}\right)^2 + (X_1 + X_2')^2\right]}$$



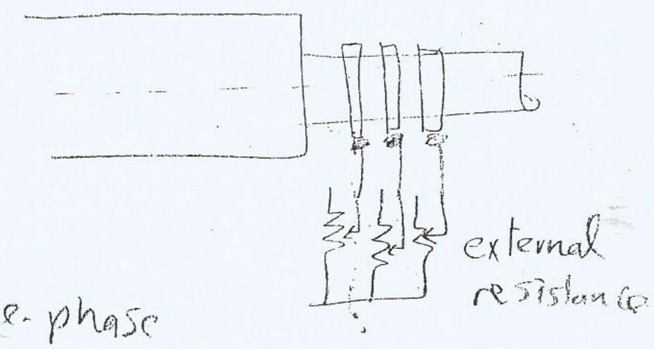
i.e. $\rightarrow$ $$= \frac{3V_1^2}{2W_s\left[r_1 + \sqrt{r_1^2 + (X_1 + X_2')^2}\right]}$$

T_{max} not depend on r_2'

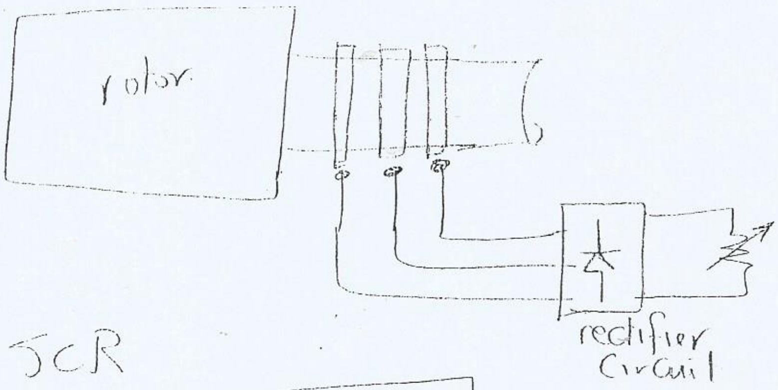
5 Done

starting of slip ring IM

using external rotor resistance

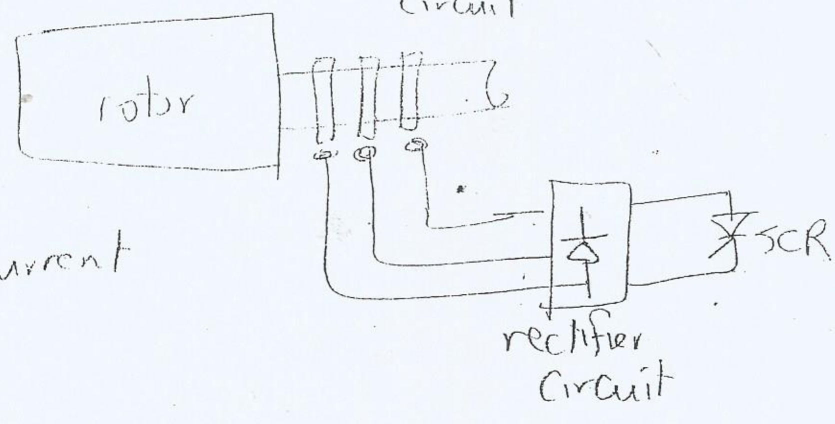


large copper losses in Three-phase resistance. So we can improve it by using one resistance and rectifier circuit



or using SCR

by changing firing angle of SCR the value of starting current can be reduced

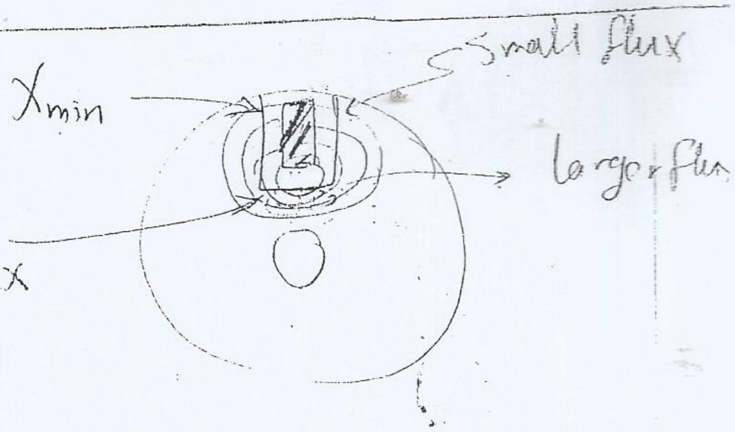


Effect of Flux on reactance value for Deep bar motor

$L \propto \phi$

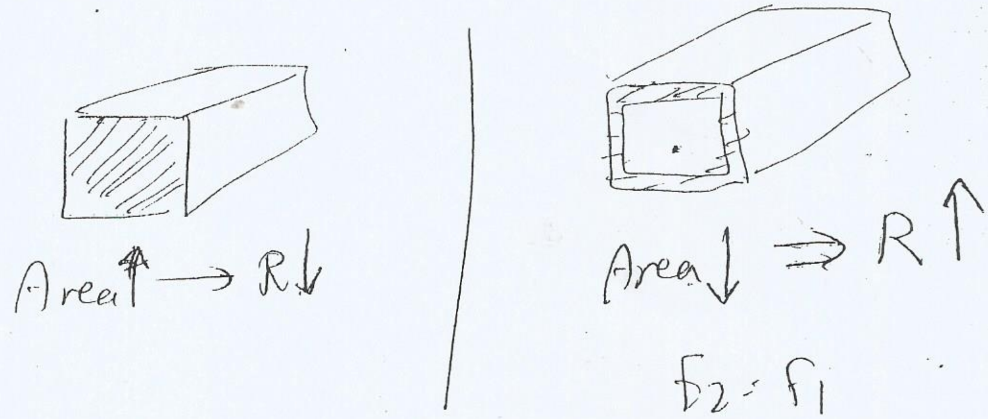
$L = \frac{N\phi}{I}$

$X = 2\pi f \cdot L$



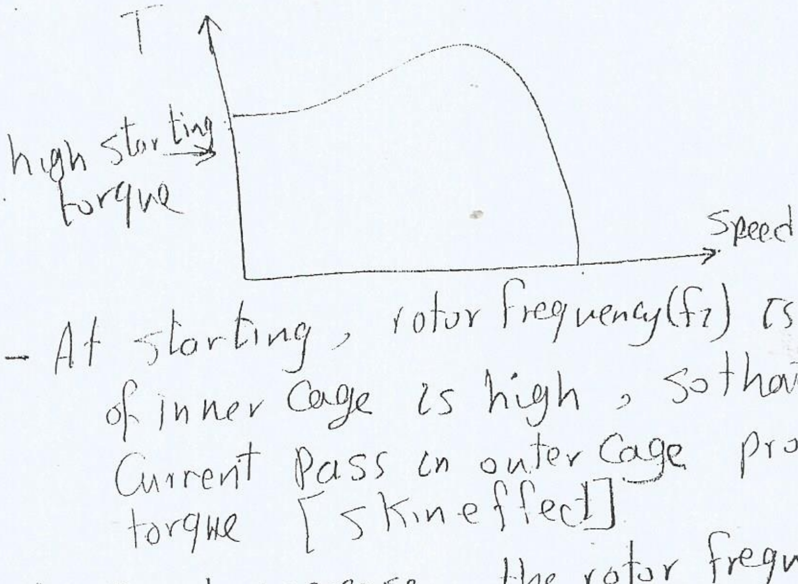
Effect of skin effect of starting resistance

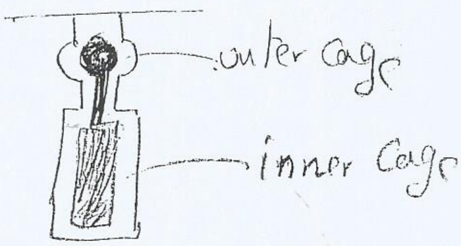
- At starting $f_2 = Sf_1 \Rightarrow (f_2 = f_1) \Rightarrow$ high rotor frequency so that rotor resistance is high producing high starting torque. [due to skin effect current pass in the surface
- when motor speed increase so that f_2 decrease producing low rotor resistance.



double Cage I.M

- The main disadvantage of squirrel-cage I.M, is its poor starting torque due to low rotor resistance, so must increase rotor resistance but it give low mot efficieny
- to achieve high starting torque with high running efficieny we will use double cage motor
- outer cage has high resistance and low reactance to resistance ratio
- Inner cage has low resistance and high reactance to resistance ratio



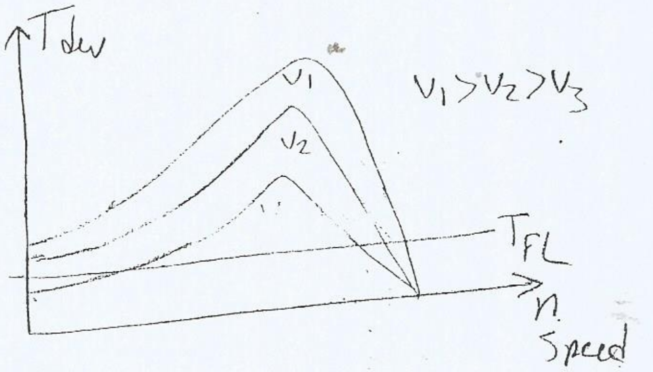


- At starting, rotor frequency(f_2) is high, so reactance of inner cage is high, so that most of starting current pass in outer cage producing high starting torque [skin effect]
- As speed increase, the rotor frequency decrease, so reactance and impedence of the inner cage decrease and become very small under normal operation, most of motor current pass in the inner cage producing low resistance & high efficiency

→ Speed control of 3-phase Induction motors

A) Squirrel Cage IMs

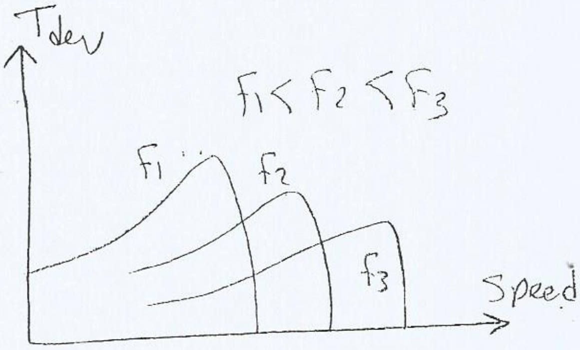
1) Voltage control



used for range $(10 \rightarrow 15\%)$ of rated speed

⇒ low starting torque [$T_{st} < T_{FL}$] ⇒ motor will not rotate

2) Frequency controls



$E = 4.44 f_1 \phi N k_w = V$

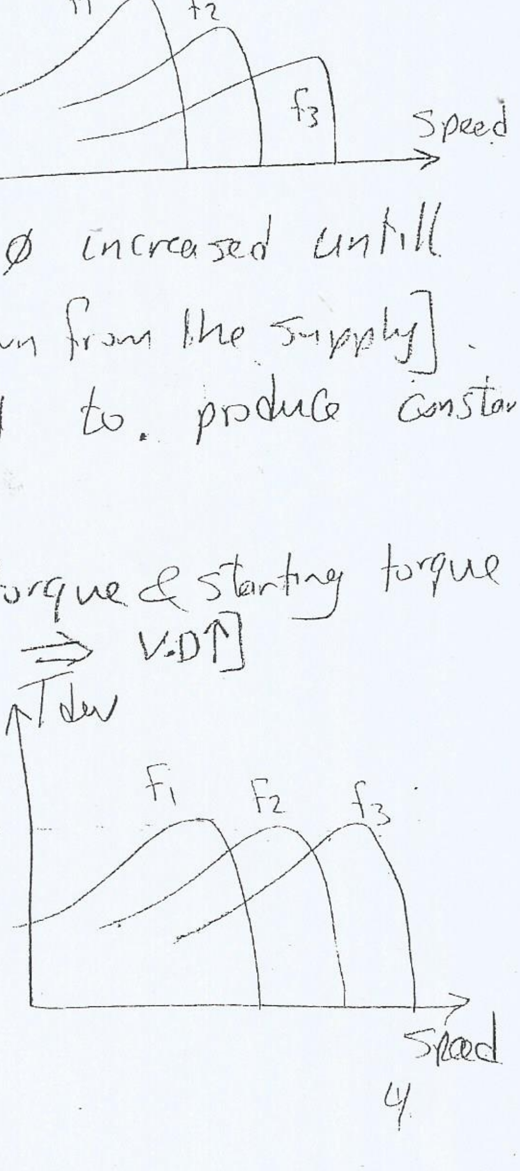
$n_s = \frac{60f}{P}$

→ by reducing frequency, the flux ϕ increased untill saturation. [large current drawn from the supply].

So must use $\frac{V}{F}$ = constant to produce constant flux (ϕ)

→ by increasing frequency Max torque & starting torque will be reduced. [also $X\uparrow \Rightarrow V.D\uparrow$]

3) Voltage frequency control (V/F)



⇒ constant maximum torque

⇒ no saturation problem

Total induced emf / phase on Sychronous machine = E

$E = 4.44 f \phi T K_w$

f = frequency Hz

ϕ = flux wb

T = number of turns / phase

K_w = winding Factor = $K_p K_d$

K_p = chording factor

K_d = distribution factor

$K_p = \cos(\beta/2)$

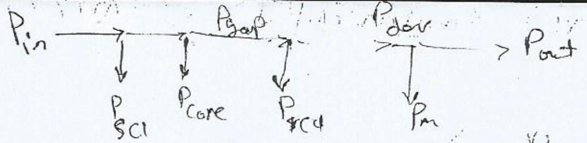
$$K_d = \frac{\sin(q\,\alpha_s/2)}{q \sin(\alpha_s/2)}$$

β = chording angle

q = number of slot / pole / phase

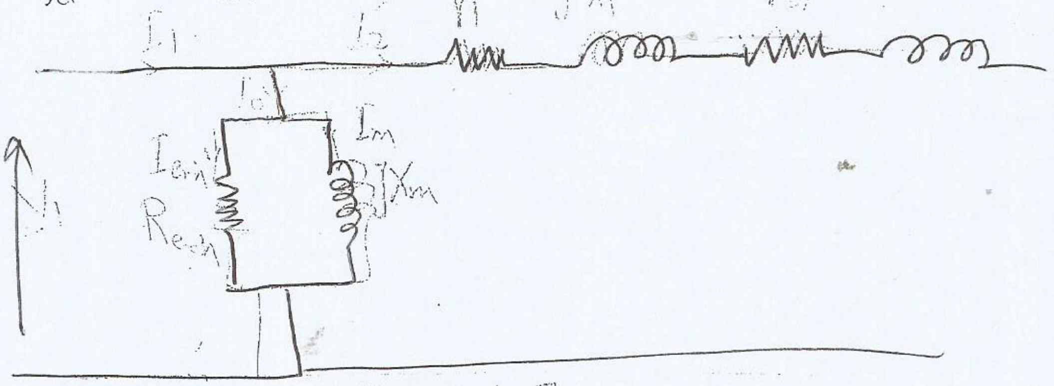
α_s = slot angle

$$\alpha_s = \frac{180}{m \cdot q}$$, m = number of phases



3

Done



V_1 = input voltage [stator]

I_1 = " Current [stator]

I_0 = No load Current

I_m = magnetizing Current

I_{erh} = eddy & hysteresis current

I_2 = rotor Current

I_2' = rotor Current refer to stator $\Big\}$ $\boxed{I_2' = \frac{I_2}{a}}$

r_1 = stator resistance

X_1 = " reactance

r_2 = rotor resistance

X_2 = " reactance

r_2' = " resistance refer to stator $= a^2 r_2$

X_2' = " reactance " " $= a^2 X_2$

$$\bar{I}_0 = \bar{I}_{erh} + \bar{I}_m = \bar{V}_1\left[\frac{1}{R_{erh}} - J\frac{1}{X_m}\right] = |I_0| \angle -\phi_0$$

$$|I_0| = \sqrt{|I_{erh}|^2 + |I_m|^2}$$

$\cos\phi_0$ = no load Power Factor [lag]

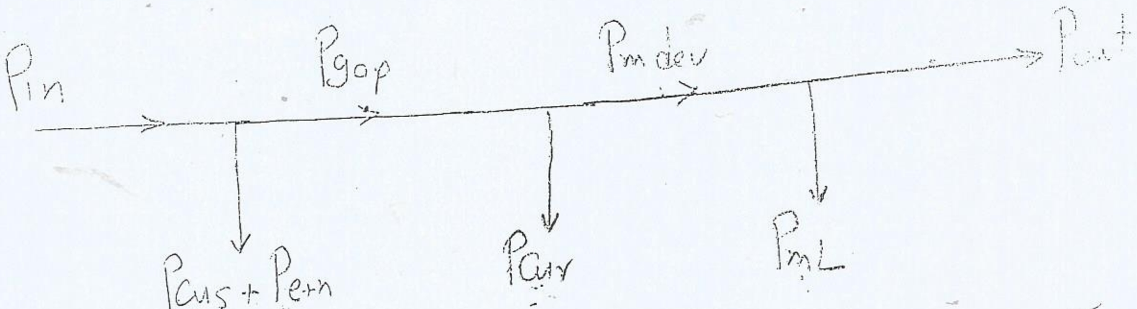
$$I_2' = \frac{V_1}{(r_1 + r_2'/s) + j(x_1 + x_2')} = |I_2| \angle$$

$$|I_2| = \frac{V_1}{\sqrt{(r_1 + r_2'/s)^2 + (x_1 + x_2')^2}}$$

$$\bar{I_1} = \bar{I_2'} + \bar{I_0} = I_1 \angle \theta_{I_1} \leftarrow \text{lag } (-)$$

$$\text{Input Power factor} = \cos(\theta_{V_1}^{0} - \theta_{I_1}) \rightarrow \text{lag}$$
$$= \cos \phi_1$$

Power flow diagram



$$P_{in} = \text{input stator power} = \sqrt{3}\, V_1 I_1 \cos \phi_1 \quad [V_1, I_1 \text{ line}]$$
$$= 3 V_1 I_1 \cos \phi_1 \quad [V_1 \,\&\, I \text{ phase}]$$

$$P_{cus} = \text{stator copper losses} = 3 I_1^2 r_1 \rightarrow \underline{\text{Exact}}$$
$$= 3 I_2'^2 r_1 \rightarrow \text{Approximate}$$

$$P_{eth} = \text{iron loss [eddy \& hystresis]}$$

P_{gap} = Air gap power ←
= Power delivered from <u>stator</u> to <u>rotor</u>
= input rotor power

$P_{cur} =$

$P_{gap} = 3 I_2^{\sim 2} r_2/s$

$\Rightarrow P_{cur} = s\, P_{gap}$

P_{mdev} = developed mechanical Power

$= (1-s) P_{gap}$

P_{mL} = total mechanical losses

P_{out} = output [useful] Power

η = efficiency = $\frac{P_{out}}{P_{in}}$ %

T_{dev} = developed torque = $\frac{P_{mdev}}{\omega} = \frac{(1-s) P_{gap}}{(1-s)\,\omega_s}$

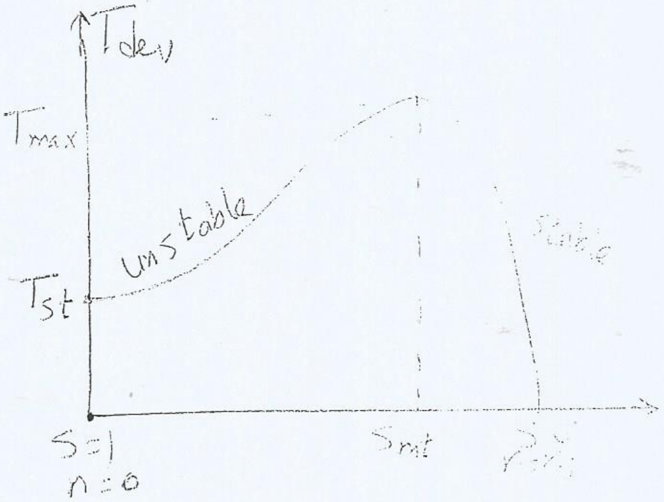
$T_{dev} = \frac{P_{mdev}}{\omega} = \frac{P_{gap}}{\omega_s}$ (N.m)

or $T_{dev} = P_{gap}$ [Sychronous. watt]

T_{mL} = mechanical loss torque = $\frac{P_{mL}}{\omega}$ (N.m)

$$T_{dev} = \frac{P_{gap}}{W_s}$$

$$T_{dev} = \frac{3\, V_1^2\, r_2/s}{W_s\left[(r_1 + r_2/s)^2 + (X_1 + X_2)^2\right]}$$



At starting $(S = 1)$

At max torque $S = S_{mt}$

$$S_{mt} = \frac{r_2'}{\sqrt{r_1^2 + (X_1 + X_2')^2}}$$

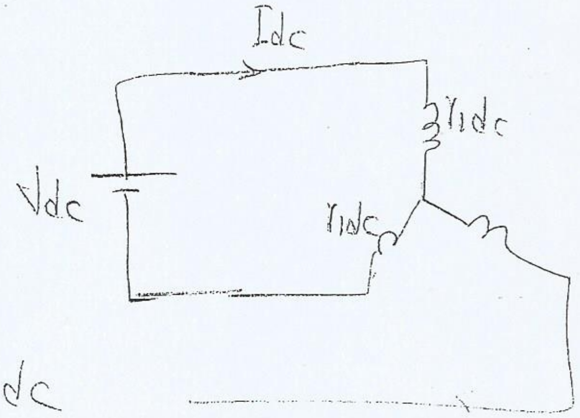
3 Determination the Parameter of the Equivalent Circuit

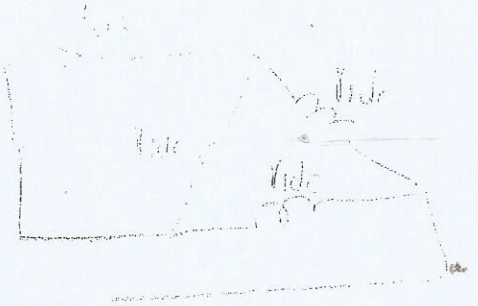
1] Dc test

$$r_{dcline} = \frac{V_{dc}}{I_{dc}}$$

$$r_{1dc} = \frac{1}{2} r_{dc\,line}$$

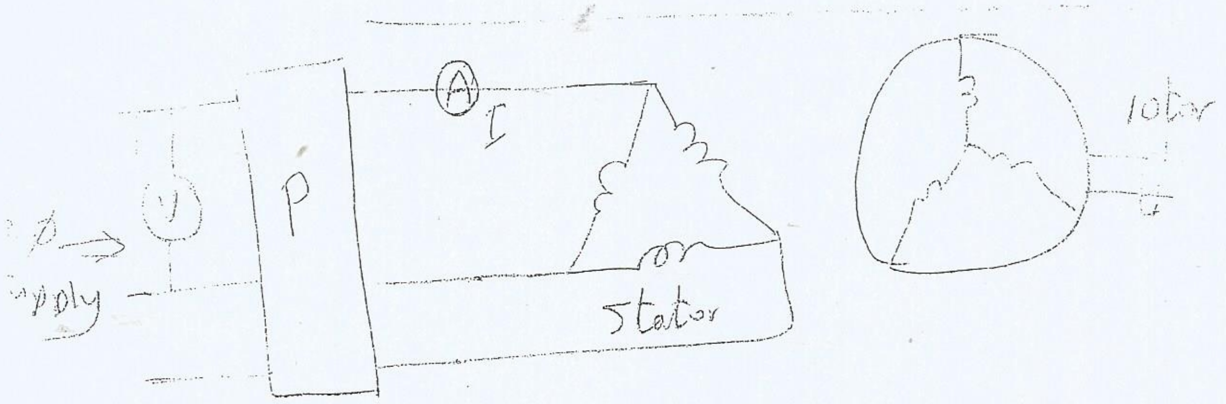
$$r_{1ac} = \text{skin effect} * r_{1dc}$$





$r_{dc} = \frac{3}{2} r_{dcline}$

$r_{ac} =$ (skin effect) $* r_{dc}$



2] No load test

$n \simeq n_s \Rightarrow s = 0$

$I_o, V_o, P_o \Longrightarrow$ phase

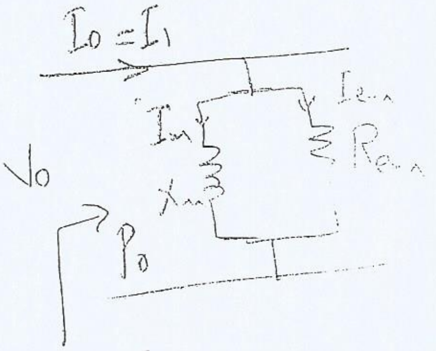
$\cos \phi_o = \frac{P_o}{V_o I_o}$

$I_{exh} = I_o \cos \phi_o =$

$I_m = I_o \sin \phi_o =$

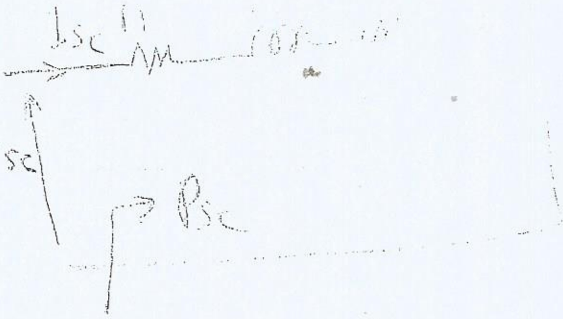
$R_{exh} = \frac{V_o}{I_{exh}}$

$X_m = \frac{V_o}{I_m}$



Blocked Rotor test

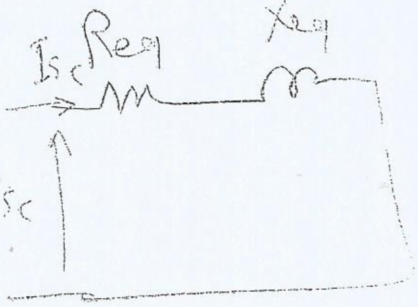
$I_o <<< I_{sh}$



$R_{eq} = r_1 + r_2'$

$X_{eq} = X_1 + X_2'$

$I_{sc}, V_{sc}, P_{sc} \Longrightarrow$ phase



$R_{eq} = \dfrac{P_{sc}}{I^2_{sc}}$

$Z_{eq} = \dfrac{V_{sc}}{I_{sc}}$

$X_{eq} = \sqrt{Z^2_{eq} - R^2_{eq}}$

usually: $X_1 = X_2' = \dfrac{X_{eq}}{2}$

$r_2' = R_{eq} - r_1 \longleftarrow$ dc test

To achieve max torque at starting $\Rightarrow$ connect external rotor resistance

$$s_{mT} = 1 = \frac{r_2' + R_{ex}}{\sqrt{r_1^2 + (X_1 + X_2')^2}}$$

$P_e = K_e f^2 B_m^2$

f - Frequency

B_m - max Flux

$P_h = K_h F B_m^x$

x - $1.5 \longrightarrow 2.5$

take x 1.6

$E = 4.44 f B_m A T \Rightarrow B_m \propto \frac{E}{F}$

$P_e = K_e' f^2 \left(\frac{E}{F}\right)^2 = K_e' E^2$

$P_e = K_e' E^2$

$P_h = K_h' f \left(\frac{E}{F}\right)^{1.6} = K_h' F^{-0.6} E^{1.6}$

$P_h = K_h' F^{-0.6} E^{1.6}$

$\frac{P_{e2}}{P_{e1}} = \left(\frac{E_2}{E_1}\right)^2$

$\frac{P_{h2}}{P_{h1}} = \left[\frac{F_1}{f_2}\right]^{0.6} \left(\frac{E_2}{E_1}\right)^{1.6}$

Generated Electric Power as a Sine wave

For transformer $\phi = \phi_m \sin \omega t$

Farady law $e = -N \dfrac{d\phi}{dt}$

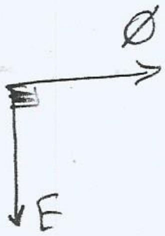
$e = -N \omega \phi_m \cos \omega t$

$e = \omega N \phi_m \sin(\omega t - \pi/2)$

$e = E_{max} \sin(\omega t - \pi/2)$

$E_{max} = 2 \pi f N . \phi_m$

$E_{rms} = \dfrac{E_{max}}{\sqrt{2}} = \dfrac{2\pi f}{\sqrt{2}} \phi_m N = 4.44 f \phi_m N$



So Induced emf lag flux by $\pi/2$

* تفاضل ال sine يعطي sine بنفس التردد وزمن الدورة

---

for induction machine

$E = 4.44 \, f \phi N \, K_w$

K_w = winding Factor $= K_p . K_d < 1$

K_p = chording factor [pitch]

K_d = distribution factor

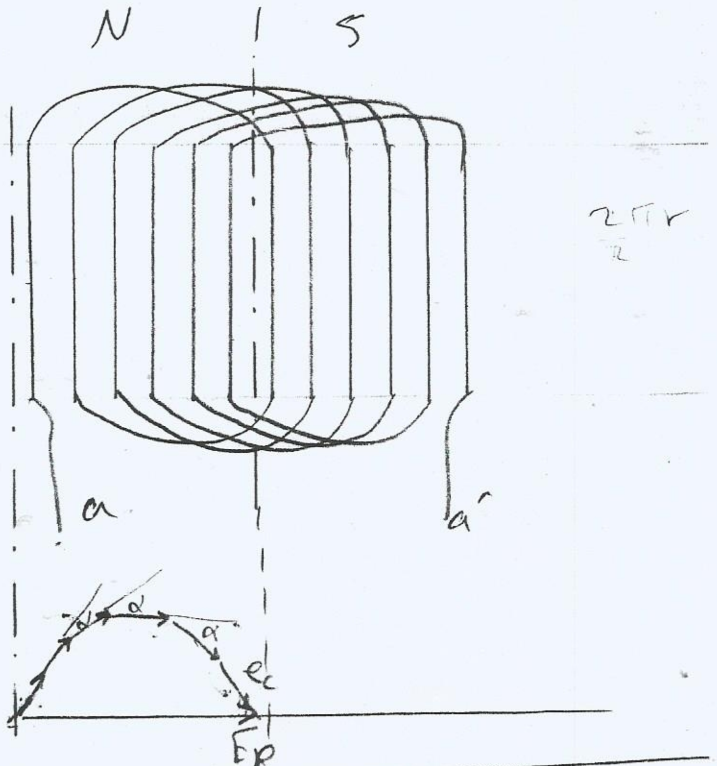
Calculation of Distribution Factors

1. Single-phase machine

Assume
$2p = 2$
number of slot $= 12$

For discrete number of slots

$K_d = \_\_\_\_\_\_\_\_$



$\frac{2\pi r}{2}$

$$K_d = \frac{\text{vectorial Sum of EMF}}{\text{Arthematic Sum of EMF}}$$

$$= \frac{E_R}{6 e_c}$$

For large number of slots

$$K_d = \frac{E_R}{\left(\frac{\pi}{2} E_R\right)}$$

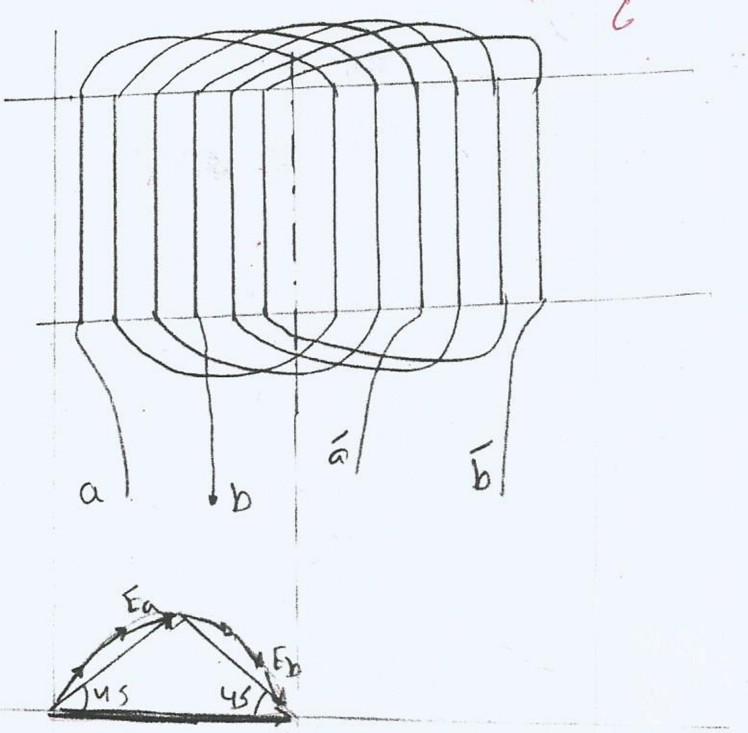
محيط نصف دائرة

$$K_d = \frac{E_R}{\frac{2\pi E_R}{2}}$$

$$\frac{2\pi E_R}{2}$$

$$K_d = \frac{2}{\pi}$$

2. two phase machine



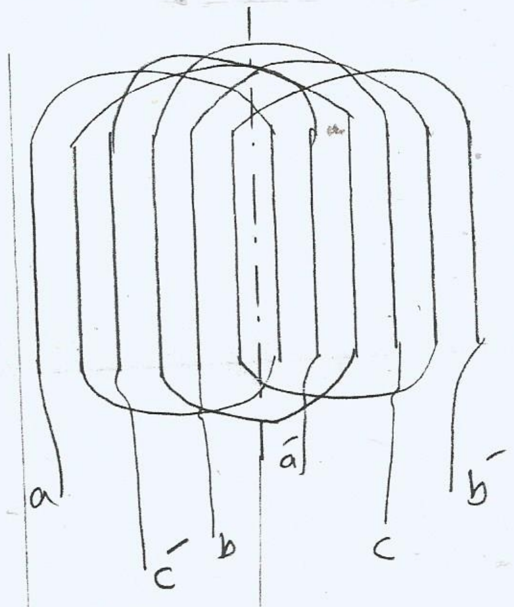
$$E_a = E_R \cos 45 = \frac{E_R}{\sqrt{2}}$$

$$K_d = \frac{E_a}{3 e_c} = \frac{E_a}{\left(\frac{\pi}{2} E_R\right) * 1/2}$$

$$= \frac{E_R/\sqrt{2}}{\left(\frac{\pi}{2} E_R\right) * 1/2} = \sqrt{2}\left(\frac{2}{\pi}\right)$$

$$K_{d2\phi} = \sqrt{2}\, K_{d1\phi}$$

∴ EMf in 2-phase increased by 42% from that in Single phase.



3) Three-phase machine

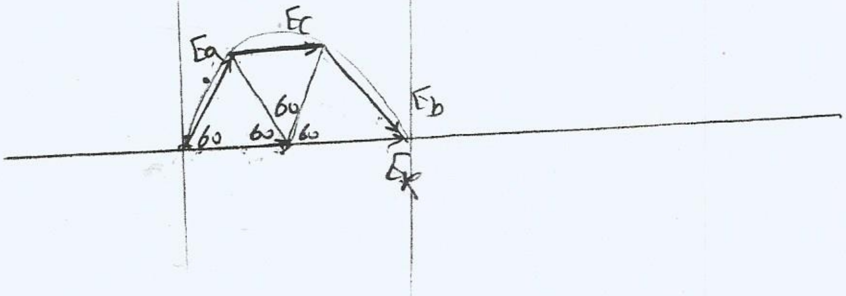
$$E_a = \frac{E_R}{2}$$

$$K_d = \frac{E_a}{2 E_c}$$

$$= \frac{E_a}{\left(\frac{\pi}{2} E_R\right) * 1/3}$$

$$= \frac{E_R/2}{\left(\frac{\pi}{2} E_R\right) * 1/3}$$

$$= \frac{3}{2}\left(\frac{2}{\pi}\right)$$



$$K_{d3\phi} = 1.5\ K_{d1\phi}$$

So emf increased by 50% from Single phase

Why we prefer to use 3-phase system?

For same Current rating

$$P_{1\phi} = E_R I \cos\theta$$

$$P_{2\phi} = 2 E_a I \cos\theta$$

$$= 2 \frac{E_R}{\sqrt{2}} I \cos\theta = \sqrt{2}\ P_{1\phi}$$

$$P_{3\phi} = 3 E_a I \cos\theta = 3 \frac{E_R}{2} I \cos\theta$$

$$P_{3\phi} = 1.5\ P_{1\phi}$$

∴ Assume infinity number of phases

$$P_{\infty\phi} = (e_1 + e_2 + \overbrace{\cdots\cdots}^{\text{المحيط}} e_\infty)\, I \cos\theta$$

$$= \frac{\pi}{2} E_R \, I \cos\theta$$

$$P_{\infty\phi} = \frac{\pi}{2} P_{1\phi}$$

$$P_{\infty\phi} = 1.57\, P_{1\phi}$$

Small increase in Power with Large cost [Large number of conductor]

For discrete number of slots

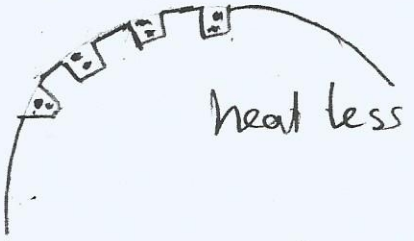
$$K_d = \frac{\sin(q\alpha_s/2)}{q\sin(\alpha_s/2)}$$ ✓

α_s = slot angle

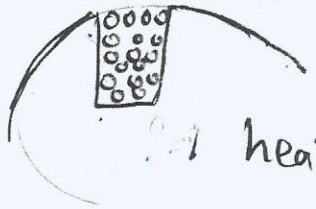
q = number of slot/pole/phase

- **Advantages of using distributed conductors**

[1]



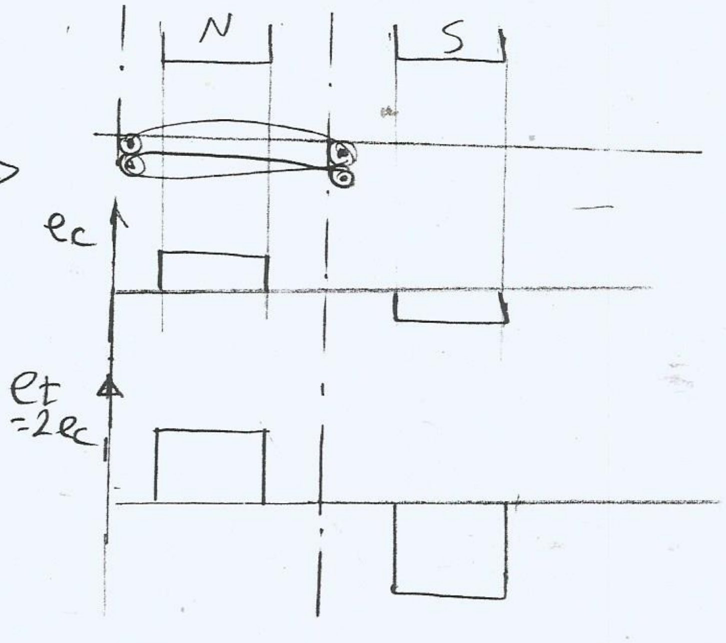
distributed conductor over more than one slot will reduce the temprature ⇒ better cooling



the temprature rise of the conductor at the slot center [hot spot point] bad cooling

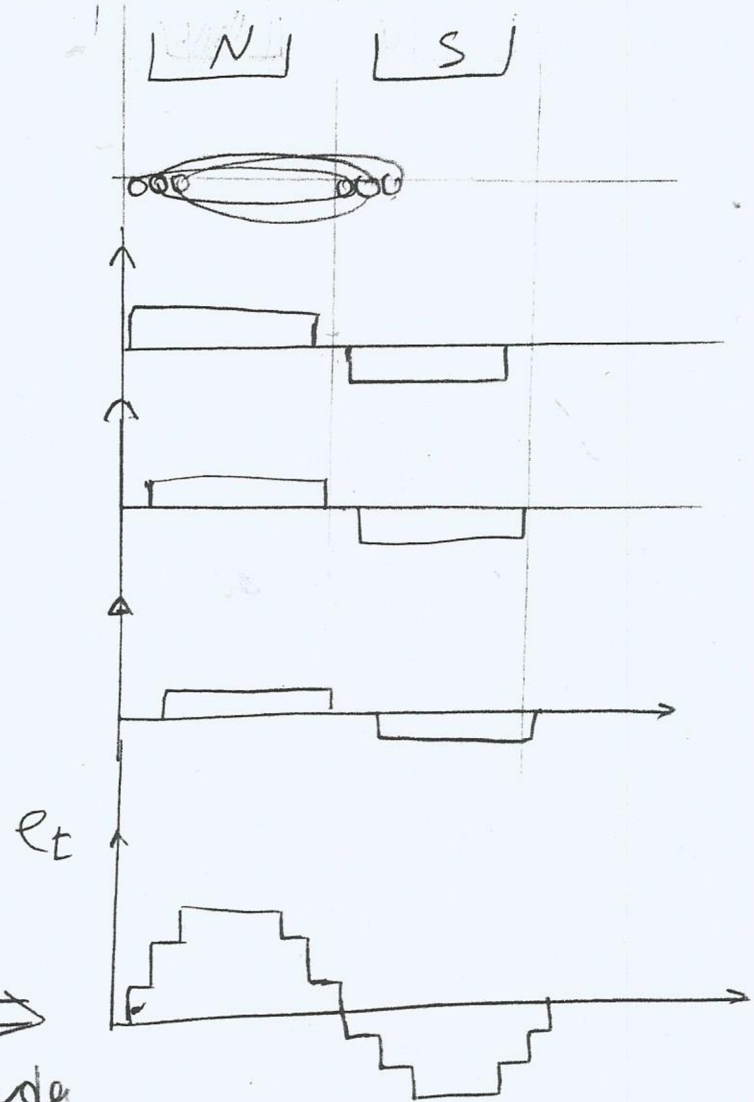
2) The waveform improved [become near to sinusoidal]

Concentric wdg ⇒



Rectangular waveform →

If wdg is distributed



⇒

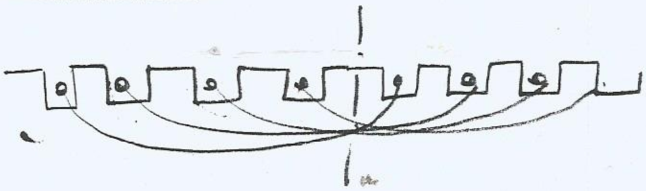
disadvantage of Distributed wdgs

reduce total emf by $K_d < 1$

Single layer & double layer wdg

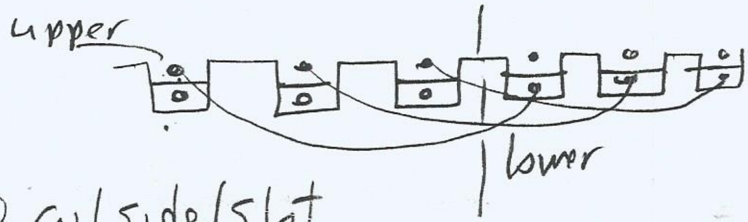
- Single layer

1 coilside/slot.



- double layer

used in chording



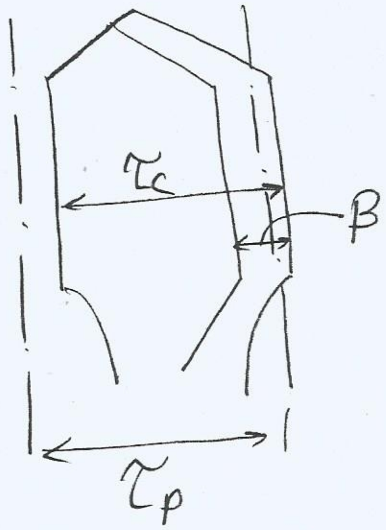
2 coil side/slot

Chording wdg.

τ_c = coil pitch

τ_p = pole pitch

$\tau_c = \tau_p \Rightarrow$ Full pitch



β = chording angle

$K_p = \cos(\beta/2)$

For n harmonic order

$K_{pn} = \cos(n\beta/2)$

in chording $\tau_c \ngtr \tau_p$

Advantage of Chording

1) the waveform of the emf is improved where chording will cancel certain order of harmonic,

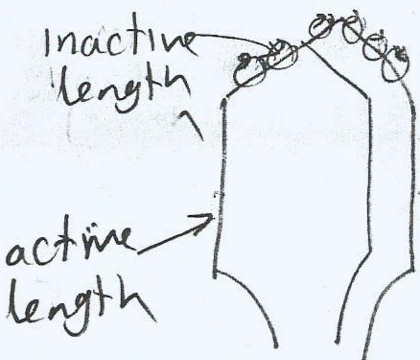
$K_{p5} = \cos(5\beta/2) \Rightarrow K_{p5} = 0$ when $\frac{5\beta}{2} = 90$

$\beta = 36$

to cancel 5th order $\Rightarrow$ must chording by 36°

2) reduce the amount of used copper so that reducing copper resistance, reduce copper loss increase efficiency

3) reduce leakage reactance [reduce inactive length]



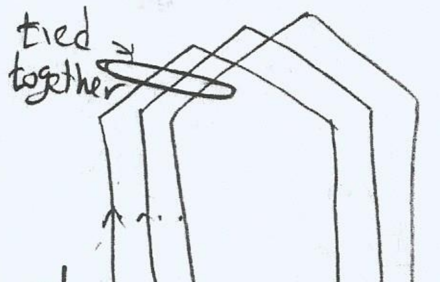
4) the mechanical strength of chorded coil is better than unchorded coil

- disadvantage of chording wdg

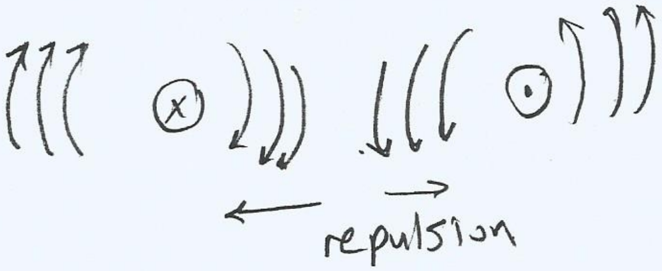
- reduce total induced emf by $K_P < 1$

- why transformer wdg must be tied from outside together.

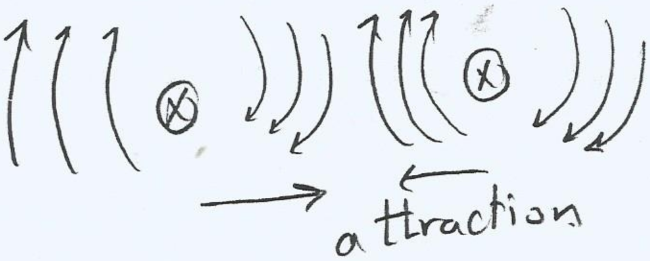
why we must fix the inactive length



when current pass on the conductor it produce flux, which produce a force may be attraction or repulsion [depend on current direction]



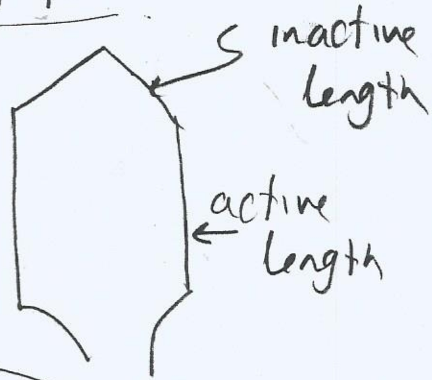
لابد من ربط الملفات
باحكام من الخارج .



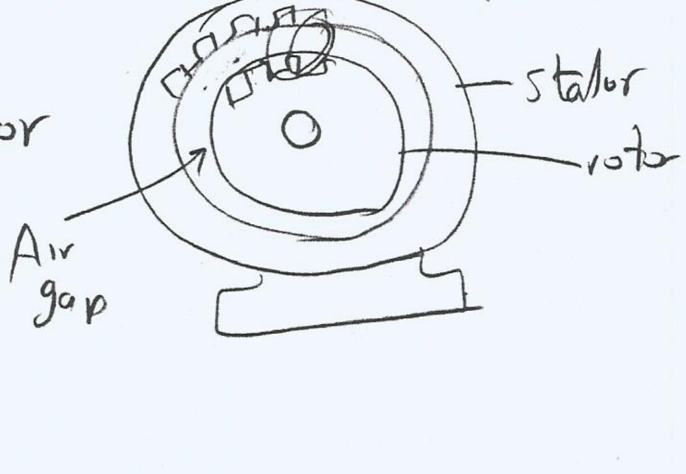
* In transformer primary & secondary current on opposite direction, so when short circuit occur in transformer large repulsion force produce so it must tied the coils together.

What is the reasons of presented leakag flux

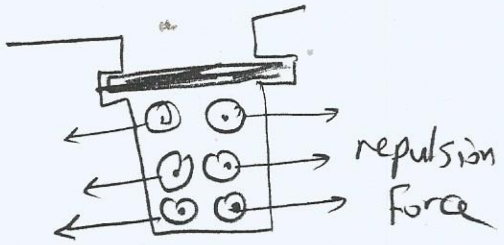
1] inactive length



2] Airgap on generator & motor
not all flux produce by stator linked with rotor but there is a leakag flux in Airgap



- Why In large scale machine must used wedg from nonmagnetic material?



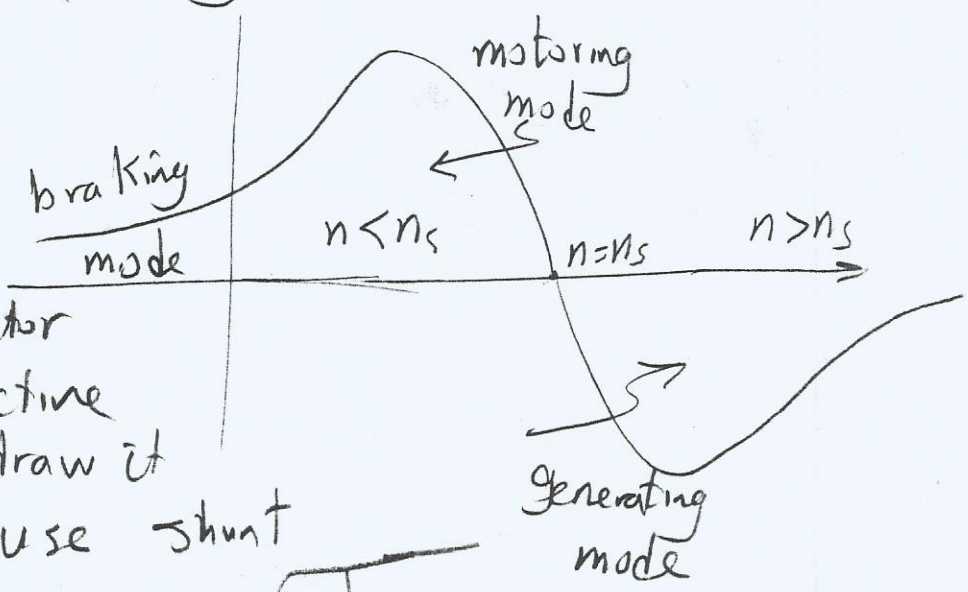
to prevent conduct to go out from slot, due to present of magnetic field, which produce a force.

- what is the meaning of transformer Power fact?

transformer hasn't meaning of P.F where it transfer power from primary circuit to secondary circuit $V_1 I_1 = V_2 I_2$

- Draw T-N Chs of Induction machine

Show generating & motoring mode



- to operate as a generator it has source of reactive Power so it may draw it from network or use shunt Capacitor